Locating tie-points on a grid

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A robust software method is described for analyzing a digitized image of a calibration grid in order to determine the location of the intersections of its grid lines or tie-points.

Light sheets are used in wind tunnels to selectively illuminate seeded particle air flows in order to capture off surface phenomena. The sheets are photographed by cameras from points outside of the tunnel windstream and are distorted by the combined effects of camera perspective, lens aberrations, and the like. Calibration grids, photographed in the wind tunnel at the same position and plane as the light sheets, provide the basis for compensating for such distortion. [1]

The intersection points of the grid image are used as tie-points for a 2-D polynomial fit and subsequent warping of the light sheet images to remove the effects of the distortions. Previously, tie points have been measured manually, but, with over a few hundred points this is both a tedious and time consuming task.

A raw grid image is often characterized by variations in shading, extraneous off-grid imagry, and poor line definition as shown in figures 1 and 2. Image pattern recognition begins with image enhancement which, simply put, suppresses noise or unwanted features while enhancing desired features. The image with the target grid is first masked to remove any extraneous image objects that may impact subsequent processing by altering the masked area to levels as close to the background level as possible.

The image is then processed to eliminate regional shading variations while also reversing the image, if necessary, to make the grid lines get the numerically higher values. Regional variations are minimized by subtracting a heavily smoothed or averaged image, which has a predominance of low frequency components, from either the original or a slightly smoothed image. The result is an image which retains the local, high frequency, components, (i.e. the lines), while suppressing the shading variation.

Having prepared the image, the strategy at this point is to get an approximate idea where the grid lines fall and of their number.

Near the top of the masked area a sub area band of the image is delineated which is 32 pixels high and equal in width to the grid image. Each 32 pixel column of this sub area is summed to form a horizontal summation array. In those parts of this array that

correspond to places where vertical lines exist the array values are sharply higher. The array is relatively insensitive to horizontal lines. The array values are truncated to remove background values.

The vertical lines of the grid in the sub area corresponding to the summation array are located by locating the peak positions in the array as shown in figure 3.

A similar process is used along the left-hand side of the grid to determine the position of the horizontal lines. Once each line has been located at some point along its length, a basis exists for estimating the position of each line intersection or tie point. The task becomes one of more precisely locating the lines at those points where they intersect. Figure 4.

No allowance has been made thus far for the angles or distortions in the line images, therefore, estimates of horizontal and vertical points are more accurate near where they were collected and less so with distance from the measurement locations. The measurements may be improved by going to each estimated position of a tie point and doing a more direct measurement in that locale.

Local searches for the actual intersection points are conducted within small windows about each estimated intersection position. As each position is accurately identified the difference or error between the estimated and actual position is used to improve the estimate of the next subsequent position. This error correction technique makes the location of even very distorted grid tie-points possible.

In the local search the horizontal and vertical lines are, again, dealt with separately. On each axis within the window the pixel values are again summed along the axis of interest. These values are again saved in an array but since only one center value is desired a weighted mean value of the array is used as the center position.

It is possible that at certain points of the original image the line definition is so poor that an accurate measure of the position of some tie points is doubtful. In such instances position information of neighboring tie points can be used to augment or even replace a poor measure. This interpolation can be done using a least squares fit of the data. Caution must be exercised, however because, except over short spans, the image positions of the tie points cannot be assumed to be strictly linear.

Once the tie-point positions have been determined they are used, along with ideal values, to calculate 2-D polynomial coefficients of the desired order to warp the image into the form of the ideal. See figures 5 and 6.

1. Stacy, Kathryn; Severance, Kurt; and Childers, Brooks A.: Computer-Aided Light Sheet Flow Visualization,, AIAA 24th Fluid Dynamics Conference (Orlando, Florida), July 6, 1993.
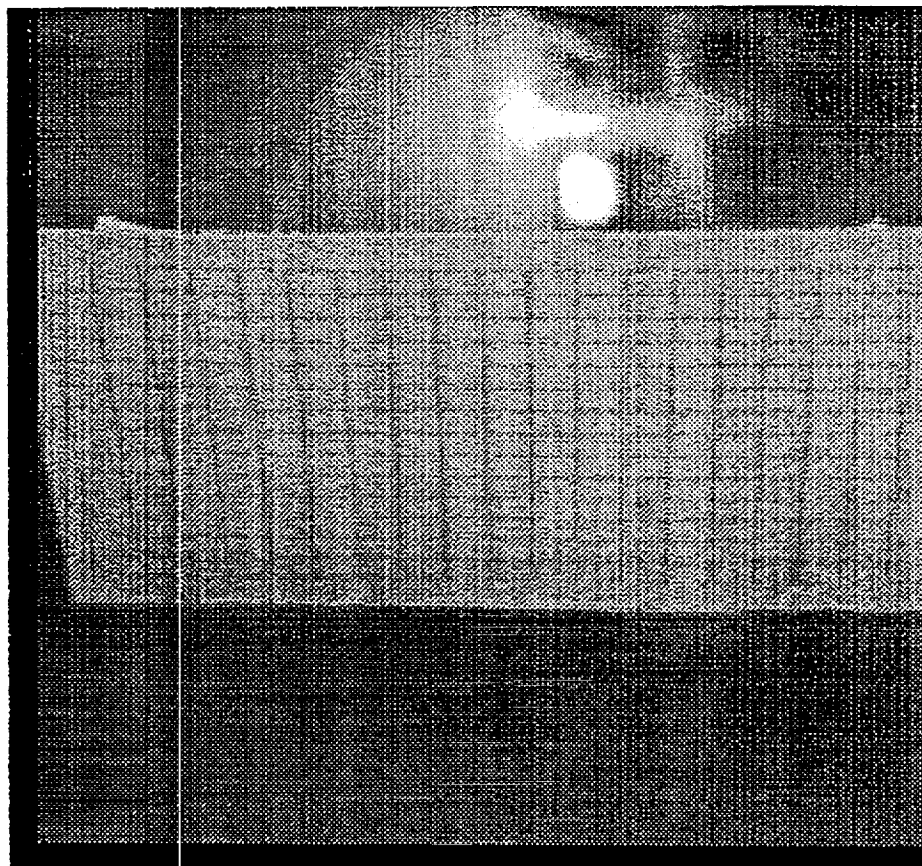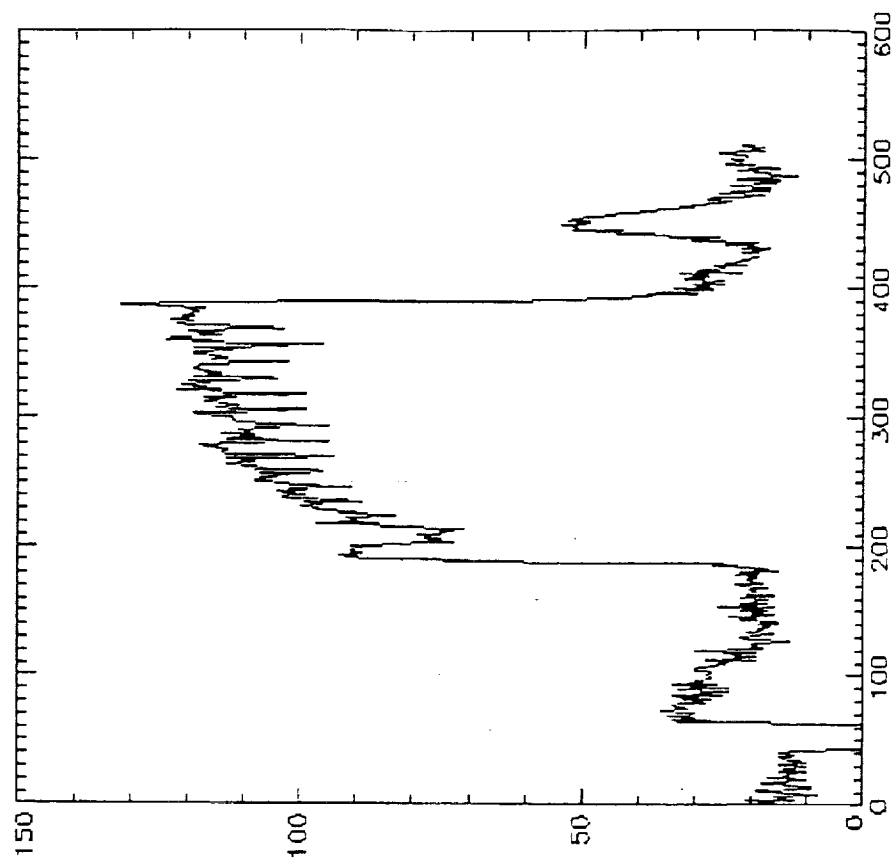
Figure 2.   Scan line detail along white line
shown in figure 1.

Figure 1.   Calibration grid with distortion.
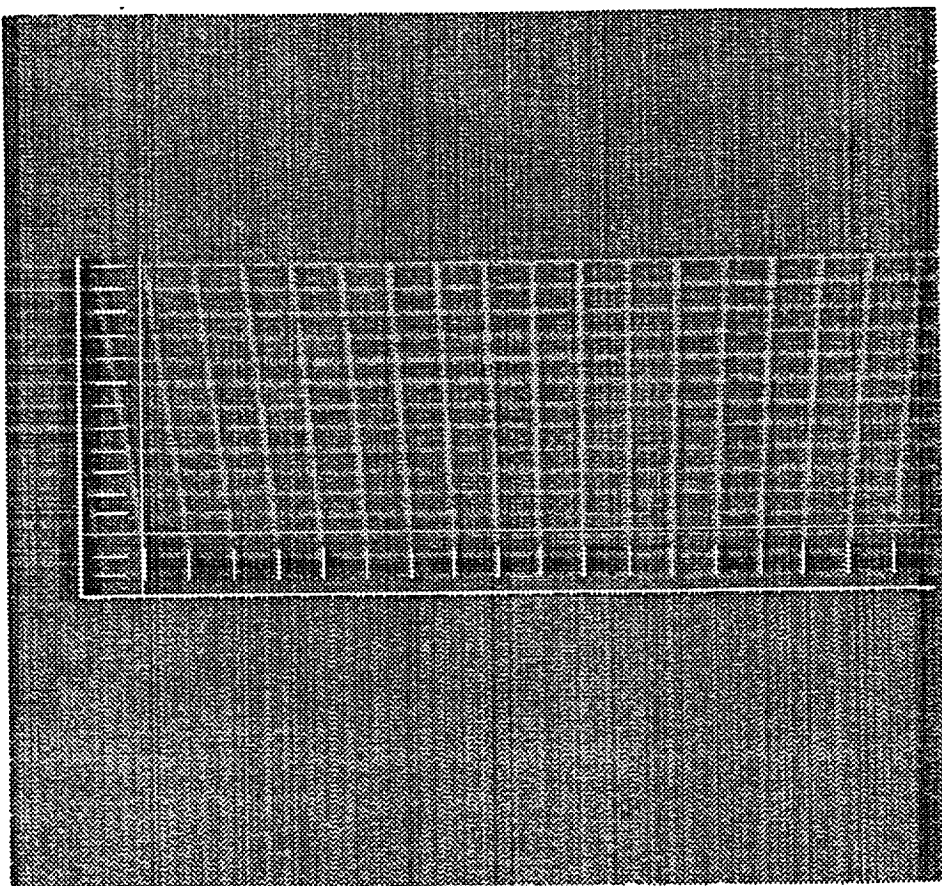
Figure 4. Overlay of enhanced grid line image with line markers in the regions where they are measured.

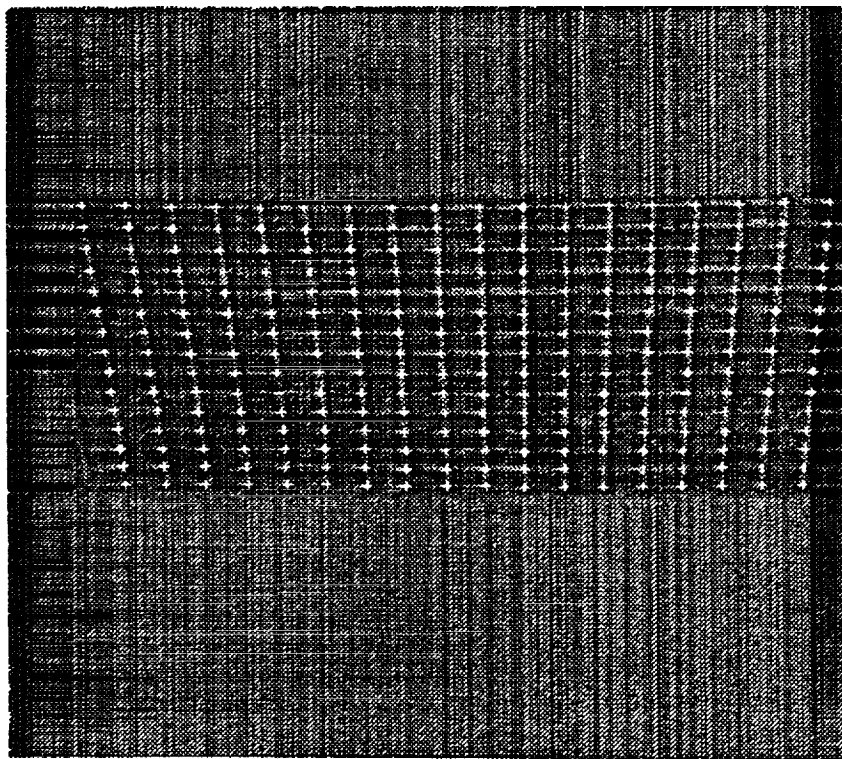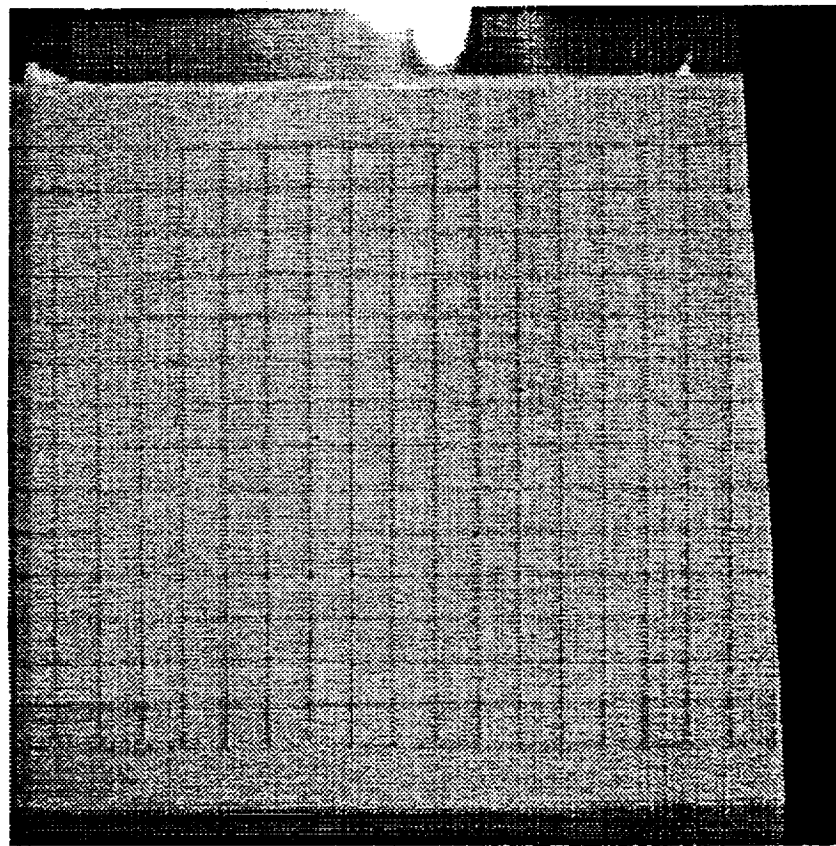Figure 3. Horizontal summation array. Peaks correspond to vertical lines.

Figure 6.   Calibration grid warped to remove distortion.

Figure 5.   Enhanced image overlain with markers at individual tie-points.